



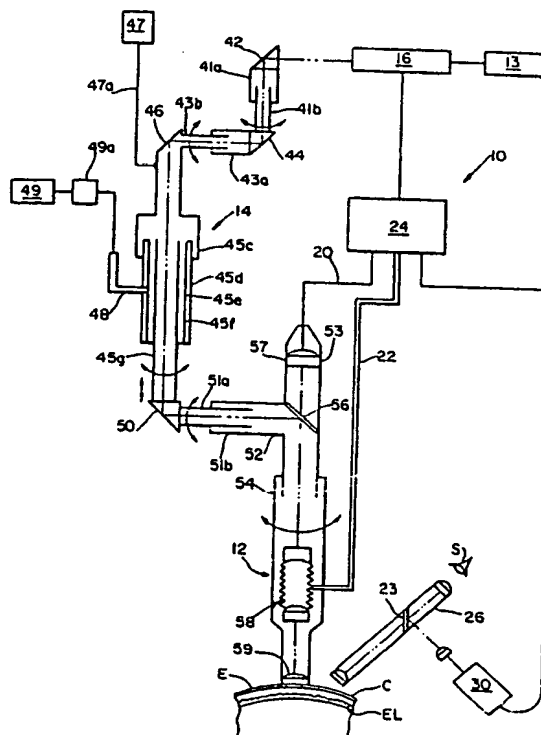
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁴ : A61F 9/00, A61C 1/00 A61B 17/36, B23K 26/04	A1	(11) International Publication Number: WO 89/11260 (43) International Publication Date: 30 November 1989 (30.11.89)
(21) International Application Number: PCT/US89/02094 (22) International Filing Date: 18 May 1989 (18.05.89) (30) Priority data: 195,843 19 May 1988 (19.05.88) US (71) Applicant: REFRACTIVE LASER RESEARCH & DEVELOPMENT PROGRAM, LTD. [US/US]; 7810 Louis Pasteur, San Antonio, TX 78229 (US). (72) Inventors: TABOADA, John ; 12530 Elm Country, San Antonio, TX 78230 (US). POIRIER, Robert, H. ; 3458 River Path, San Antonio, TX 78229 (US). (74) Agent: LAVINE, Irvin, A.; Mason, Fenwick & Lawrence, 1225 Eye Street, N.W., Suite 1000, Washington, DC 20005 (US).		(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent). Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: HANDPIECE AND RELATED APPARATUS FOR LASER SURGERY AND DENTISTRY

(57) Abstract

Apparatus is provided for effecting medical or dental surgery, and to a related method. The subject body on which surgery is to be performed has a reference thereon or therein identified, such as a layer in the cornea, or a surface of a tooth. A handpiece (12) has a longitudinally extending first optical path and a second, transverse optical path, with a dichroic reflector (56) at the juncture of the paths. The handpiece contains a variable focus lens (58) and a fiberoptic bundle (20) is connected axially to the distal end of the handpiece. Light is passed through the fiberoptic bundle into the handpiece to illuminate the site. The image of the site is passed through the variable focus lens and to the fiberoptic bundle, and thence to a control apparatus (24) for adjusting the variable focus lens so as to provide for focussing of the treatment laser beam at a predetermined distance from the reference. A laser beam is passed to the handpiece by way of the second optical path, and thence through the variable focus lens, which focuses the beam to a localized spot which is at a predetermined distance from the reference: the distance may be zero, where, for instance, the reference is the surface of a tooth which is to be ablated. The handpiece is supported by an articulating arm system which provides six degrees of freedom of motion. A method of performing surgery comprising determining by focus condition measuring equipment the distance of a reference in a subject body, adjusting a variable focus lens by control signals proportional to the focus condition measured, and passing a laser beam through the variable focus lens in the adjusted position.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FI	Finland	ML	Mali
AU	Australia	FR	France	MR	Mauritania
BB	Barbados	GA	Gabon	MW	Malawi
BE	Belgium	GB	United Kingdom	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IT	Italy	RO	Romania
BJ	Benin	JP	Japan	SD	Sudan
BR	Brazil	KP	Democratic People's Republic of Korea	SE	Sweden
CF	Central African Republic	KR	Republic of Korea	SN	Senegal
CG	Congo	LI	Liechtenstein	SU	Soviet Union
CH	Switzerland	LK	Sri Lanka	TD	Chad
CM	Cameroon	LJ	Luxembourg	TG	Togo
DE	Germany, Federal Republic of	MC	Monaco	US	United States of America
DK	Denmark	MG	Madagascar		
ES	Spain				

- 1 -

HANDPIECE AND RELATED APPARATUS
FOR LASER SURGERY AND DENTISTRY

5

10

15

BACKGROUND OF THE INVENTION

20 The present invention relates to a handpiece and related apparatus for performing surgery and dentistry with a laser.

 Applications of laser technology to medicine and dentistry have been suggested for well over a decade. 25 Advances have been rapid, and laser devices are now commonly found, not only in operating rooms, but in the offices of physicians. Among the more widely used applications of laser technology in medicine is in the field of eye surgery.

30 Among the uses of lasers in the medical field are cutting, cauterizing, melting and ablating tissue. It

- 2 -

material to the greatest degree, one or more conditions must be met, including (a) the delivery of the laser energy in high powered pulses or with high continuous power; (b) the laser must be tuned to the extreme violet end of the spectrum where the photon absorption is high in organic substance; or (c) the laser must be tuned to the extreme infrared end of the spectrum where absorption of radiation by water, a major constituent of living tissue, is a factor. As is known, condition (a) functions through non-linear optical processes such as dielectric breakdown, which creates a finely localized absorption site because the resulting plasma is usually opaque to the laser beam. These noted conditions are extreme conditions and have resulted in the inability of some or all optical components to handle this extreme laser energy delivered.

In the care and treatment of eyes, it has been recognized that in some cases an eye may depart from a normal or "perfect" configuration, particularly in that the outer surface of the eye, the cornea, is not curved properly, but has some excessive steepness which cause kerataconus or myopia, resulting in impaired vision. Proposals have been made to correct this imperfection by changing the internal structure of the stroma layer of the cornea by the application of heat and/or radio frequency energy, but these proposals have had significant deficiencies. For example, Doss et al U.S. Patent 4,326,529 attempts to achieve the correction of

- 3 -

corneal irregularities by keratoplasty technique, in which the central stroma is heated with a radio frequency electrode probe, to break collagen crosslinks, to contract the collagen which is a part of the clear corneal medium. The method disclosed in Doss et al has the disadvantage that the heat deposition is not easily localized in the three-dimensional space of the cornea.

Roussell et al U.S. Patent 4,409,979 provides apparatus for treating the human eye with laser radiation, and for viewing the site. Reflectors and prisms are provided to conduct light from a light source to the site, passing eccentric to the optical path; an image is conducted from the site to a viewing instrument, such as a microscope, centrally of the optical path. A beam from a laser is caused to strike the central part of a mirror which is movable between an operative position and a retracted position. In the operative position, the mirror directs the laser radiation to the site, generally along the optical path. In the retracted position, the mirror is removed from the optical path, permitting passage of the aforementioned light beam and observing beam. A weak laser is also provided, whose beam passes in a path eccentric to the optical path. A manually adjustable focussing lens is provided in the light paths to focus the light from the light source and the laser radiation. The arrangement presents a problem which

- 4 -

requires the provision of a rotatable tube for housing beam splitters and reflectors which are part of the optical path of the light source beam, the observing beam, and the weak laser beam. Hence, manipulation of the rotatable tube and manual adjustment of the focussing lens are required to achieve the desired viewing and focussing, prior to the energization of the power laser and the moving of the mirror into operative position to direct the power laser beam to the site. The method of Roussell et al has the disadvantage that it cannot be moved with the freedom of a handpiece with six degrees of freedom. In addition, the method requires the intervention of an operator to establish the focal site of the laser energy delivery.

Muckerhide U.S. Patent 4,316,467 discloses the use of a laser for treating birthmarks or lesions on the skin, in which control of the power or energy level of a laser is effected by receiving radiation reflected from the lesion by a fiberoptic bundle: a control circuit senses the intensity corresponding to the color intensity of the region to which the laser beam is directed and varies the energy of the laser.

Goldenberg U.S. Patent 4,641,912 discloses an excimer laser system used for angioplasty, and includes a pair of optical fibers, one for obtaining an image of the atherosclerotic plaque to be ablated by the laser energy, a second optical fiber being provided for

- 5 -

lasing the plaque. A video camera and monitor are utilized to acquire and display an image of the plaque.

Karlin et al U.S. Patent 4,583,539 discloses a system for performing surgery on the eye using a CO₂ laser source and an articulated arm structure, the laser energy being delivered through a probe which is connected to the articulated arm structure and which is insertable into an eye.

Kimura U.S. Patent 4,266,549 discloses a laser scalpel including a probe through which light may be directed to illuminate the optical site: where a tumor is to be subjected to lasing, a picture or graphic representation may be obtained. An adaptor is provided at the tip of the probe to engage the tissue at or adjacent the tumor, to establish the distance of the focussing lens of the probe to the tumor to be laser.

Remy et al U.S. Patent 4,289,378 discloses an apparatus for adjusting the focal point of a working laser beam onto a microscopic target region of a transparent biological object. Use is made of an auxiliary laser beam having a wavelength within the visible range, and through joint manual focussing of the laser beams, the location of focussing of the working beam at a particular locus at a desired depth within the transparent biological specimen is achieved.

The aforementioned disclosures, however, lack provision for a direct contact plano convex lens for the delivery of the laser energy to loci at very small

- 6 -

ranges from the surfaces. They also lack provision for a contact lens surface to cover the cornea while the adjacent lower tissue is being irradiated and also to serve as a guide surface for hand held instruments.

5 These limitations are overcome by the present invention as will be made evident below.

Among the patents disclosing a dental handpiece for directing laser energy to a tooth is Ota et al U.S. Patent 4,503,853. In this patent, the handpiece
10 includes a centrally located optical fiber through which the laser beam is passed to the tooth. The handpiece is provided at its distal end with a distance spacer to engage the tooth and provide a fixed spacing between the tooth and the end of the optical fiber to
15 regulate the amount and strength of irradiation of laser beams from the laser source. Myers et al U.S. Patent 4,521,194 discloses a method of removing incipient carious lesions and/or stains from teeth by the application of a laser beam from a source such as a
20 yttrium-aluminum-garnet laser. In neither of these patents is there provision for autofocussing of the laser beam, nor is there a provision for viewing the site through the handpiece. These aforementioned apparatus also lack provision for the delivery of high
25 peak power TEM(00) laser mode radiation, as this radiation would normally destroy the fiber-optic delivery devices. For example, five millijoules Q-switched YAG laser pulses would destroy the single mode

- 7 -

fiber-optic ends.

SUMMARY OF THE INVENTION

An apparatus and method for performing laser surgery is disclosed, in which a focussed laser beam is directed by a handpiece to an operational site, and is automatically focussed, so that the tissue modifying (ablation, cutting, melting, etc.) effect of the laser beam is located at a desired locus along the axis of the beam in the subject body. The handpiece which is provided is supported by a novel articulated arm system which permits the handpiece to have six degrees of freedom. The novel arrangement which uses prisms permits the delivery of high peak power laser radiation ranging from the ultraviolet to the infrared. Within the handpiece there is provided a dichroic reflector which receives laser radiation passed through the articulating arm system from a laser source, the laser radiation (including a concentric alignment beam) entering the handpiece along an optical path at right angles to the optical path which is substantially coincident with the axis of the handpiece. A system of focussing lenses is provided in the handpiece. A light source is optically connected to the handpiece through a fiberoptic bundle, which is connected to the proximal end of the handpiece, light passing axially along the handpiece axis and through the dichroic reflector and the variable focus lens to the site, the observation light from the site passing through the focussing lens

- 8 -

and the dichroic reflector into the fiberoptic bundle and to a control system which causes automatic focussing of the adjustable lens, to focus the laser radiation at a preselected depth in the subject body related to a reference or benchmark in the body, which may be, for example, the endothelial cell layer of a cornea. The control system may take the form of an image scanner which delivers a signal to an error signal generator having a reference signal source therein, and generating an error signal to an electromagnetic impulser which controls a fluid cylinder. The fluid cylinder has a piston in it moved by the electromagnetic impulser, and is connected by a flexible conduit to a variable volume chamber of the variable focus lens. The handpiece lower member may be rotated about the handpiece axis, and the handpiece is rotatable about the above mentioned lateral axis. The fiberoptic bundle and the fluid conduit are both flexible, permitting unrestrained movement of the handpiece. Among the objects of the present invention is the provision of apparatus and method of laser surgery in which there is automatic focussing of a laser beam relative to the operational site.

Another object is the provision of such method and apparatus including a handpiece in which the depthwise positioning of the focus spot of a focussed laser beam is automatically controlled relative to a reference feature.

- 9 -

Another object of the present invention is to provide an apparatus which includes a handpiece for delivery of laser energy and for permitting observation of the site along the axis of the handpiece.

5 Another object of the present invention is to provide an apparatus and method which include a plano-convex sapphire lens with the plano side to the tissue to be treated.

A further object is to provide a thin hand contact
10 lens to cover the cornea to serve as a guide surface.

Still another object of the present invention is the provision of an apparatus which provides to a surgeon simultaneous, superimposed images of an operating site, derived from direct observation through
15 a viewing instrument, and from a superimposed video image acquired through a handpiece at the operational site.

A further object of the present invention is to provide an apparatus which delivers laser radiation to
20 an operational site through a handpiece while providing the handpiece with six degrees of freedom of motion for orientation of the handpiece relative to the operational site.

Yet a further object of the present invention is
25 the provision of an apparatus which delivers laser radiation to an operational handpiece with a minimum of encumbrance, minimum friction and inertia, and optimum counterbalancing using a single boom and a novel air

- 10 -

bearing beam conduit.

Other objects and many of the attendant advantages of the present invention will be readily understood from consideration of the following specification,
5 claims and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of an apparatus in accordance with the present invention.

Fig. 1A is a detailed view of a part of the
10 apparatus of Fig. 1, and a contact lens on a cornea.

Fig. 2 is a schematic view showing portions of the apparatus of Fig. 1, in greater detail.

Fig. 3 is a view, partly in section, of a dental handpiece in accordance with the present invention.

15

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings, wherein like or corresponding reference numerals are used for like or corresponding parts throughout the several views, there is shown in Fig. 1 an apparatus 10 for performing laser
20 surgery on an eye E. There is shown, in particular, the transparent cornea C having within it the endothelial layer EL, and with a contact lens 60 on the cornea; the lens 60 is optional. The herein disclosed apparatus utilizes the depth of the endothelium as a
25 reference or landmark for achieving the delivery of laser radiation at a concentrated focus spot within the cornea at a desired depth relative to the endothelium, regardless of the contour of the outer surface.

- 11 -

Because the contact lens 60 has the novel arrangement of having the plano side to the cornea, the focussing is extremely accurate and localized. In order to locate the concentrated or focussed spot of the laser beam at the precise location, i.e., depth or distance from the corneal surface, the endothelial layer is utilized as a reference for a focussing system and a variable focus lens, described below. Although the herein disclosed method and apparatus are particularly applicable to treating the cornea with laser energy, the method and apparatus herein disclosed are not necessarily limited to that application.

The apparatus 10 includes a handpiece 12 adapted to be held in the hand of a surgeon. Handpiece 12 is supported by an articulating arm system 14, which receives energy from an ablative laser 16. There may also be provided a relatively weak, aligning laser 18. The laser 16 may be, for example, a high repetition rate, Q-switched YAG TEM₀₀ mode system having an energy per pulse of about three millijoules and a rep rate of the order of 2,000 pulses per second. The laser 16 is coaxially traversed by the beam from the aligning laser 18, which is preferable a visible, low powered CW laser, and is used for achieving beam component alignment, or optionally as a source of illumination for the reference endothelial cell layer. Typically, the laser 18 is a three milliwatt helium neon laser. The laser beam in the Gaussian TEM₀₀ mode can be

- 12 -

diffraction limited focussed to a minimum spot size on the order of about 10 microns. The novel prism arrangement of the articulating system of the present invention permits any number of high power very
5 ablative lasers to be used, such as an excimer laser for wavelengths in the far UV range, or an f-center laser for wavelengths in the near IR region. Preferably, a movable platform or carriage (not shown) supports the lasers 16 and 18 and the articulating arm
10 system 14.

Connected to the handpiece 12 is a flexible coherent fiberoptic bundle 20 and a flexible conduit 22, which are in turn connected to a monitoring and control system 24. A viewing instrument 26, such as a
15 microscope, is provided, containing a beam splitter 28, and having adjacent to it a TV monitor 30. A surgeon S views through this instrument as shown.

The articulating arm system 14 is shown in schematic form, and provides for six degrees of
20 movement of the handpiece 12. There is provided an outer tube 41a which is fixed, and in practice extends upwardly from prism 42. An inner tube 41b is axially rotatable relative to the outer tube 41a. This permits the remainder of articulating arm system 14 to rotate
25 in a horizontal plane. The outer tube 41a is suitably anchored and supported, as mentioned above. Fixedly connected at right angles to the inner tube 41b is an outer tube 43a, having within it a prism or other

- 13 -

reflector 44. Axially rotatable in the outer tube 43a is an inner tube 43b. A tube 45a is connected at right angles to the inner tube 43b, and in it is a reflector 46. A counter-weight 47 is connected to the tube 45a by an arm 47a. Tube 45a has an enlarged end 45c in which is mounted a tube 45d, and within the tube 45d there is a perforated tube 45e of smaller diameter, providing a chamber 45f between them. Air or gas is supplied to the chamber 45f through a conduit 48 supplied with air from an air or gas source 49 through a pressure regulator 49a. An inner tube 45g is located within the perforated tube 45e, and is rotatably and axially movable, being supported on an almost frictionless air cushion between the inner tube 47b and the perforated tube 45e.

The inner tube 45g has at its outer end a reflector 50, and is secured at right angles to an inner tube 51a, there being an outer tube 51b which is axially rotatable with respect to it. The outer tube 51b forms part of a T-shaped housing 52 which includes a tube 53 transverse to the tube 51b. A lower tubular member 54 is axially rotatable relative to the tube 53.

Within the housing 53 are a dichroic reflector 56, and adjacent the proximal end of handpiece 12 and within housing 53 is a relay lens 57. Within the tubular member 54 is a variable focus lens generally designated 58 and at its distal end is a plano-convex coupling lens 59, in engagement with the plano side to

- 14 -

the outer surface of cornea C. In Fig. 1A, the plano side of lens 50 is in engagement with the surface of a hard contact lens 60 through which the radiation passes and which serves as a guide surface.

5 Referring now to Fig. 2, there is shown the handpiece 12, including the dichroic reflector 56, which is located at the juncture of an optical path through the tubes 51a and 51b, and an optical path along the axis of tubes 53 and 54. The variable focus
10 lens 58 includes for example a negative lens 61 movable axially on guides 62, and a positive lens 63 fixed in position by a locking ring 64. A flexible bellows 66 is hermetically attached to the lenses 61 and 63: flexible conduit 22 extends from the flexible bellows
15 66, and is in fluid communication with the chamber formed by the lenses 61 and 63 and the flexible bellows 66.

The monitoring and control system 24 includes a lens 72 in alignment with an end of the fiberoptic
20 bundle 20, and dichroic reflectors 73 and 74. A light source 76 is in alignment with dichroic reflector 73, and provides light to the operating site, through the lens 72, and fiberoptic bundle 20, and thence into the handpiece 12, passing through relay lens 57, dichroic
25 reflector 56, the variable focus lens 58, and coupling lens 59. Alternatively, the illumination provided by the alignment laser 18 (Fig. 1) can serve to provide the image of the endothelial cells, in which case

- 15 -

optical element 75a, 75b, which are bandpass filters passing only the wavelength of the alignment laser, are utilized. A television camera 77 is in alignment with the partial reflector 74, to receive images of the site, TV camera 77 being connected to the TV monitor 30 (Fig. 1).

Also forming a part of the monitoring and control system 24 is an image scanner 78, which receives an image from the endothelial layer EL. The image scanner, by means of out-of-focus sensings, measures the departure of the optical system comprised of the variable focus lens 58, and lenses 59 and 57 from focus on the reference layer EL, i.e., it measures the focus condition. The scanner 78 delivers a signal representative thereof to an error signal generator 79. Error signal generator 79 includes an internal reference standard, such as a pre-set voltage, and generates an error signal in proportion to the difference between the reference voltage and the voltage supplied from image scanner 78. The generated error signal is supplied to an electromagnetic impulser 81 which, in response to the signal received, moves a piston rod 82 into or out of a fluid cylinder 83. The fluid cylinder 83 is fluid connected with the variable volume chamber of variable focus lens 58 by the flexible conduit 22. Thus, the focus of the variable lens is changed in accordance with the variation of the thickness of the cornea C. The

- 16 -

automatic adjustment of the variable lens with thickness variations of the cornea C assures that the laser beam focal point lies at a predetermined fraction of the corneal thickness since the focus condition of the variable lens system affects the surgical laser beam.

In use of the apparatus 10 shown in Figs. 1 and 2 of the drawings and hereinabove described, the handpiece 12 is maneuvered into position so that the coupling lens 59 at the distal end thereof is in engagement with the outer surface of the cornea C of the eye E under observation and treatment, as shown in Fig. 1. Alternatively, as shown in Fig. 1A, the engagement surface may be a contact lens 60 positioned to cover the cornea and to provide a transparent guide surface. The positioning of handpiece 12 is facilitated by the articulating arm system 14, which permits six degrees of freedom of movement of handpiece 12. Thus, the handpiece 12 may be moved or translated, along three mutually perpendicular axes, and may be rotated about three mutually perpendicular axes. As will be appreciated, rotational movement will be effected by the axial rotational movement provided by the inner and outer tubes 41a, 41b, etc., and linear and rotational movement is facilitated by the structure including the tubes 45d and 45g, and the air bearing construction including the perforated tube 45e.

Assuming that the cornea C has a relatively normal

- 17 -

thickness at the place where it is engaged by the coupling lens 59, the focus distance of the benchmark endothelial layer EL will be "normal" and consequently the image scanner will detect a sharp image of layer EL; when the signal generated by image scanner 78 is compared by error signal generator 79 with the internal reference standard, error signal generator 79 will not produce an error signal. Consequently, there will be no change made to the variable focus lens 58, and when the laser 16 is fired, there will be produced a very high energy density, highly localized spot, at a precise and automatically determined distance, in relation to the endothelial layer EL. As may be desirable, the laser is not fired when the foregoing condition is not obtained. The handpiece 12 will be caused by the surgeon to move over the outer surface of the cornea C, for example in a radial path as in radial keratotomy, and assuming that it engages a thickness change, it will be apparent that the plano end surface of coupling lens 59 will be moved away from the reference or benchmark endothelial layer EL. The image received by the image scanner 78 will be out of focus, and the image scanner 78 will therefore send a signal to the error signal generator 79 which will be different from the internal reference voltage of error signal generator 79. When a comparison is made, a difference between the two voltage signals occurs, and an error signal will be generated and sent to the

- 18 -

electromagnetic impulser 81, resulting in movement of the piston rod 82, and a change in the focal length of the variable focus lens 58. The correction is accomplished in an extremely short period of time, so that the firing of the laser 16, which may, as is typical, be under the control of the surgeon, be accomplished without delay. The laser beam will be focussed so as to place the high energy, small diameter focus spot in the corneal layer at a desired, predetermined distance relative to the location of the endothelial layer EL.

The surgeon, utilizing both the handpiece 12 and the viewing instrument 26, will be able to obtain an image of the site which may be substantially the same as if he were looking into the distal end of the handpiece 12. The image of the site will pass from the site through the coupling lens 59, variable lens 58, dichroic reflector 56, and relay lens 57 into the fiberoptic bundle 20, and thence through lens 72 to the beam splitter 74. The image will then pass to the TV camera 77, and be transmitted to the TV monitor 30, the image appearing via the beam splitter 28 occupies a small position of the viewing field in the viewing instrument 26. It will be appreciated that the viewing instrument 26 and the handpiece 12 may be maneuvered so as to be closely adjacent to each other, for viewing the same portion of the cornea C.

Referring to Fig. 3, there is shown a handpiece

- 19 -

120 for dental applications, handpiece 120 being shown in conjunction with teeth T upon which dental work is to be performed. The handpiece 120 comprises T-shaped housing 52 formed by outer tube 51b and tube 53 transverse to it. Lower tubular member 54 is shown, rotatable with respect to tube 53, and having within it the variable focus lens 58. Also shown in handpiece 120 are the dichroic reflector 56 and relay lens 57, with the fiberoptic bundle 20 connected to handpiece 120 at its proximal end. The conduit 22 is also shown, extending to the variable focus lens 58.

At the distal end of handpiece 20, there is a reflector 121, which may take the form of a diverting prism. The diverting prism 121 will divert the light from the light source 76 to the target area on one of the teeth T, and the image thereof will be delivered to the image scanner 78, with the optical distance from lens 58 and the straight line distance of the diverting prism 121 to the dental target determined by image scanner 78, and the focus of the light and laser beams varied in accordance therewith by the error signal generator 79, the electromagnetic impulser 81, cylinder 83, and conduit 22. Since the adjustment of the variable focus lens 58 is substantially instantaneous, the dental operator may be able to effect removal of material on the dental target even though the distance between the diverting prism 121 and the dental target will change due to either or both of

- 20 -

the following conditions. One condition is that the dental handpiece 120 may be moved so as to cause the beam to traverse a surface or region of the dental target which is curved, and the operator of the handpiece 120 will not be able to maintain the diverting prism 121 at a precise distance from the dental target as the beam is moved over the curving surface thereof. The other condition, which is also overcome by the present invention, is the inability of a dental operator to maintain the dental handpiece and particularly the diverting prism 121 at a precise distance, even from a plane surface, should such be encountered in or on the teeth T. For either of these causes or conditions, it will be appreciated that the physical distance from the diverting prism 121 to the dental target site will vary, but such variation will be sensed, and there will be caused the automatic focussing of the localized energy focus spot of the laser beam on the surface of the dental target site through the above described exemplary focussing apparatus.

The claims and the specification describe the invention presented, and the terms that are employed in the claims draw their meaning from the use of such terms in the specification. Some terms employed in the prior art may be broader in meaning than specifically employed herein. Whenever there is a question between the broader definition of such term as used in the

- 21 -

prior art and the more specific use of the term herein,
the more specific meaning is meant.

- 22 -

WHAT IS CLAIMED IS:

1. An apparatus for performing surgery by laser radiation at an operational site comprising:

(a) an elongate handpiece having first and second optical paths therein at right angles to each other,

(b) a dichroic reflector in said handpiece inclined relative to said first and second optical paths,

(c) a variable focus lens in said handpiece along said first optical path,

(d) means for directing laser radiation to said dichroic reflector along said second optical path for reflection by said dichroic reflector along said first optical path to said variable focus lens, and

(e) means connected to said handpiece for acquiring an image of the site.

2. The apparatus of claim 1, and further comprising a plano-convex coupling lens at the distal end of said handpiece along said first optical path and positioned with engaging the treatment site with the plano side to the treatment site.

3. The apparatus of claim 2, and further comprising a contact plano lens engaging said plano side of said coupling lens.

- 23 -

4. The apparatus of claim 2, wherein said plano lens is of sapphire.

5. The apparatus of claim 1, and a relay lens adjacent the proximal end of said handpiece and positioned along said first optical path for receiving an image of said site through said dichroic reflector.

6. The apparatus of claim 5, wherein said image acquiring means comprises an optical fiber having an end at the distal end of said handpiece and positioned to receive an image from said relay lens.

7. The apparatus of claim 1, and further comprising means for varying the focus of said variable focus lens means.

8. The apparatus of claim 1, said variable focus lens means comprising first and second lenses, means mounting one said lens in fixed position in said handpiece, means for guiding the other said lens along said first optical path, means including said first and second lenses defining an expansible chamber.

9. The apparatus of claim 8, and further comprising a source of fluid, and means for communicating said source of fluid with said chamber.

- 24 -

10. The apparatus of claim 9, and further comprising means for scanning an image of said site from said image acquiring means and for producing a signal representative of the image scanned, error
5 signal generating means for receiving said signal and for generating an error signal, and control means for receiving said error signal and for causing said source to change the volume of fluid in said chamber.

11. The apparatus of claim 1, and further
10 comprising means for receiving an image of said site from said image acquiring means and for actuating said variable focus lens means.

12. The apparatus of claim 1, and further comprising means for supporting said handpiece for
15 rotational movement about the axis of said second optical path.

13. The apparatus of claim 1, and further comprising means for supporting said handpiece for movement with six degrees of freedom.

20 14. The apparatus of claim 13, wherein said image acquiring means comprises a flexible optical fiber connected to said handpiece, and wherein said variable focus lens has a flexible conduit connected thereto.

- 25 -

15. The apparatus of claim 1, and further comprising means for sensing the departure of the focus of said variable focus lens from a reference plane,, and means for changing said variable focus lens in
5 response to the focus error.

16. The apparatus of claim 15, and further comprising a plano-convex coupling lens at the distal end of said handpiece.

17. The apparatus of claim 15, and further
10 comprising means in said handpiece on the first optical axis for receiving radiation which has passed through said variable focus lens and for passing said radiation out of said handpiece at an angle to said first optical path.

18. The apparatus of claim 17, said angle being
15 45°.

19. The apparatus of claim 1, said image acquiring means comprising a fiberoptic connected to the proximal end of said handpiece with the end thereof
20 on said first axis, a television camera and a television monitor connected to said television camera.

20. Apparatus for performing surgery upon a subject body comprising:

- 26 -

a source of laser radiation,

means for receiving laser radiation from said source and for sharply focussing said laser radiation to a localized spot at a subject body,

5 means for sensing the distance from a part of said apparatus to a reference in or on the subject body, and

means for changing the position of said localized spot relative to the reference in the subject body in response to a change in the said distance sensed by
10 said distance sensing means.

21. The apparatus of claim 20, said distance sensing means comprising second means for emitting radiation, and means for receiving emitted radiation reflected from the reference and for generating a
15 control signal to said localized spot position changing means.

22. The apparatus of claim 20, said distance sensing means comprising a low power alignment laser beam for illuminating the reference.

20 23. The apparatus of claim 21, said second radiation emitting means comprising a source of light.

24. The apparatus of claim 23, said distance sensing means comprising means for scanning an image of said reference, and means for conducting light from

- 27 -

said reference to said image scanning means.

25. The apparatus of claim 24, said localized spot position changing means comprising a variable focus lens.

5 26. The apparatus of claim 19, said apparatus further including a handpiece to be held and manipulated by a person, said position changing means comprising a variable focus lens in said handpiece.

10 27. The apparatus of claim 26, said handpiece having a dichroic reflector therein, a first optical path in said handpiece passing through said variable focus lens, means defining a second optical path in said handpiece transverse to said first optical path, said dichroic reflector located at the juncture of said
15 optical paths.

28. The apparatus of claim 27, said apparatus further comprising a fiberoptic bundle connected to said handpiece for conducting light scattered from the reference layer into and from said handpiece along said
20 first optical path.

29. The apparatus of claim 27 wherein said distance sensing means comprises said fiberoptic bundle, a source of light, means for introducing said

- 28 -

light into said fiberoptic bundle, image scanning means for receiving the image of said reference and for generating a signal, and error signal generating means for receiving said signal and for generating an error
5 signal.

30. The apparatus of claim 26, said apparatus further comprising a fiberoptic bundle connected to said handpiece to receive an image of the reference along said first optical path, said handpiece
10 comprising an elongate, generally cylindrical member having proximal and distal ends, said fiberoptic bundle having an end located at said proximal end of said handpiece and having the terminal portion thereof in alignment with the first optical axis extending
15 longitudinally through said cylindrical handpiece portion, a television camera, means for projecting an image of said reference to said television camera, and a television monitor connected with said television camera for displaying an image of said reference.

20 31. A method of performing surgery utilizing laser energy comprising:

(a) passing a light beam through a variable focus lens,

(b) sensing the focus condition of said variable
25 focus lens and an object and changing said variable focus lens to focus light on or at a predetermined

- 29 -

distance from said object,

(c) generating a laser beam, and

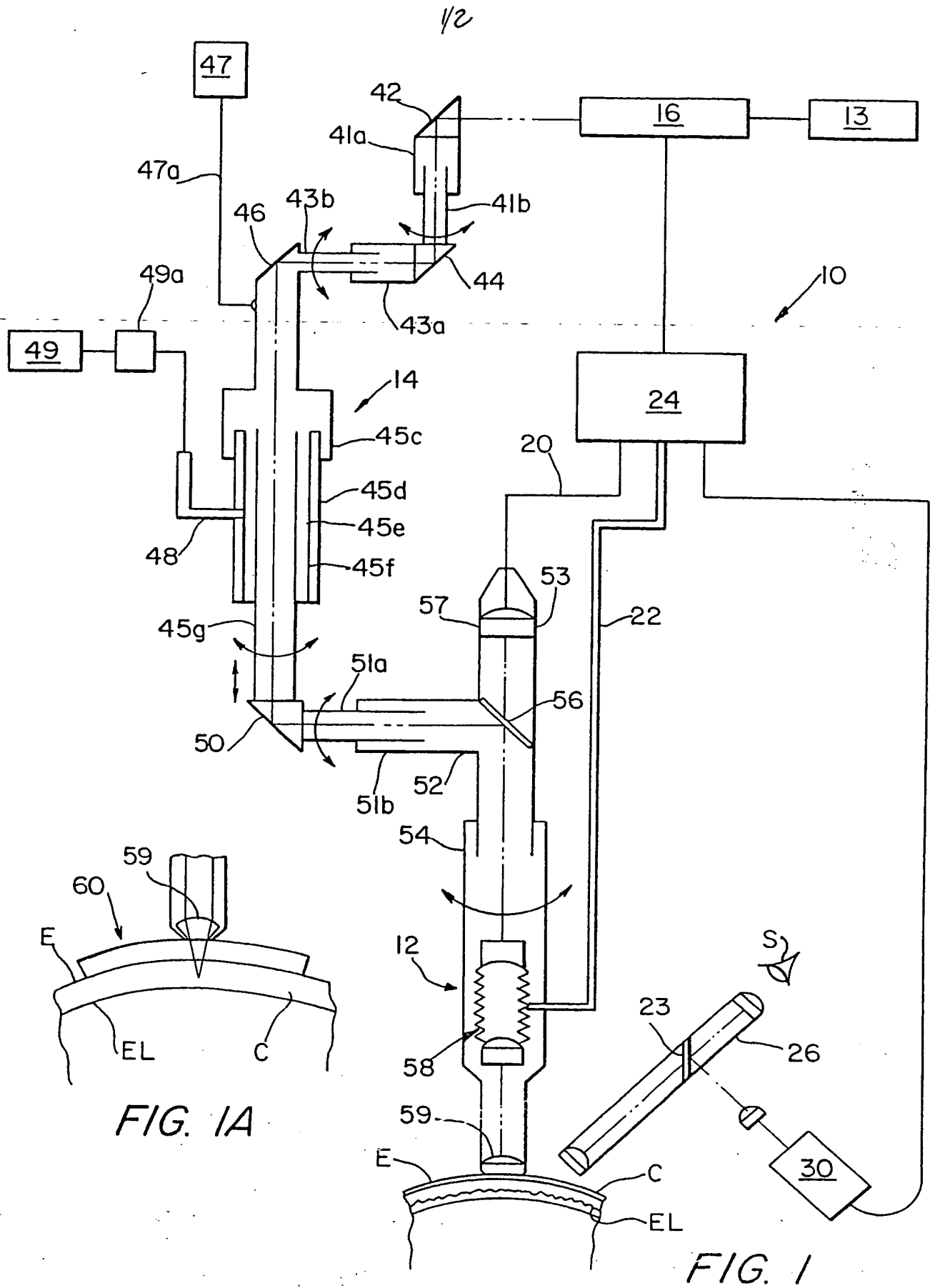
(d) passing said laser beam through said variable
focus lens after the changing of the focus of said
5 lens.

32. The method of claim 31, wherein said sensing
is by receiving light from said object and scanning
said light, and thereafter generating a signal in
response to the image scanned.

10 33. The method of claim 31, and further
comprising passing said laser beam to a dichroic
reflector located on and at an angle to the optical
axis of said variable focus lens.

34. The method of claim 31, wherein said sensing
15 is of the focus condition of said variable focus lens
with respect to a reference in a transparent anatomical
part.

35. The method of claim 31, wherein said sensing
is of the focus condition of said variable focus lens
20 and a dental target located on or in a tooth.



2/2

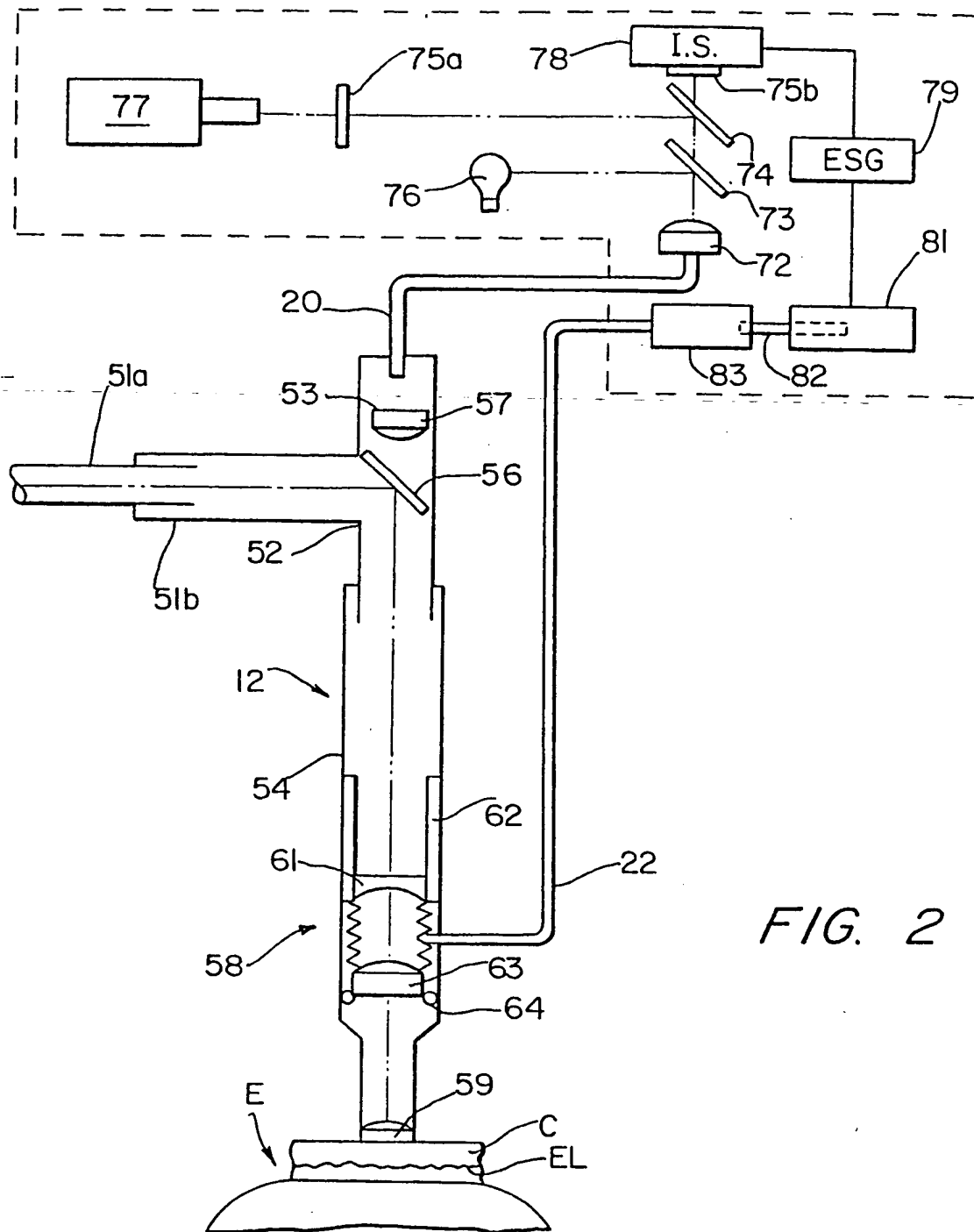


FIG. 2

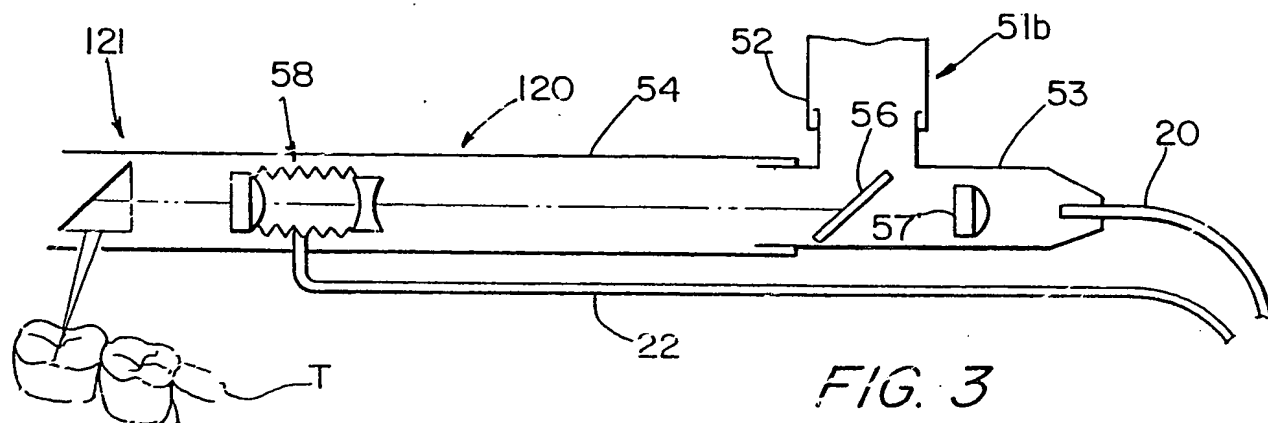


FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 89/02094

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC⁴: A 61 F 9/00, A 61 C 1/00, A 61 B 17/36, B 23 K 26/04

II. FIELDS SEARCHED

Minimum Documentation Searched *

Classification System

Classification Symbols

IPC4

A 61 B, A 61 F, A 61 C, B 23 K

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched *

III. DOCUMENTS CONSIDERED TO BE RELEVANT *

Category *	Citation of Document, ¹¹ with Indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	US, A, 3315680 (SILBERTRUST et al.) 25 April 1967 see column 2, lines 48-60; column 4, lines 25-29; figure 2 --	1
A	WO, A, 84/03220 (WEINBERG) 30 August 1984 see page 11, lines 5-10 --	1,31
A	US, A, 4583539 (KARLIN et al.) 22 April 1986 see column 10, lines 16-29; figure 1 cited in the application --	1,20,31
A	WO, A, 87/05205 (FEUERSTEIN et al.) 11 September 1987 see abstract --	20
A	WO, A, 86/04847 (FOULKES) 28 August 1986 see page 6, lines 1-12; figures -- ./.	20

* Special categories of cited documents: ¹⁰

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"Δ" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

6th October 1989

Date of Mailing of this International Search Report

06. 11. 89

International Searching Authority

EUROPEAN PATENT OFFICE

Signature of Authorized Officer

T.K. WILKES

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	US, A, 4520816 (SCHACHAR et al.) 4 June 1985 -----	

Form PCT ISA.210 (extra sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.

US 8902094
SA 28943

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 30/10/89. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 3315680		None	
WO-A- 8403220	30-08-84	DE-A, C 3306981	13-09-84
		AU-B- 576756	08-09-88
		AU-A- 2692384	10-09-84
		CA-A- 1215747	23-12-86
		EP-A- 0137835	24-04-85
		JP-T- 60500603	02-05-85
		US-A- 4719912	19-01-88
US-A- 4583539	22-04-86	None	
WO-A- 8705205	11-09-87	DE-A- 3607721	10-09-87
		DE-A- 3638226	11-05-88
		WO-A- 8705204	11-09-87
		EP-A- 0260286	23-03-88
		EP-A- 0259398	16-03-88
		JP-T- 1500009	12-01-89
		JP-T- 63503277	02-12-88
		WO-A- 8803396	19-05-88
		EP-A- 0290566	17-11-88
		JP-T- 1501527	01-06-89
WO-A- 8604847	28-08-86	EP-A- 0252082	13-01-88
		US-A- 4761534	02-08-88
US-A- 4520816	04-06-85	None	

EPO FORM 10479

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82